

1. A cooling system for a miniature x-ray tube capable of being delivered in a catheter to a desired location in a lumen of the human body, comprising:

a catheter having multiple lumens for carrying a liquid coolant, with the x-ray tube contained in a distal end of the catheter,

the x-ray tube having an anode end near the distal end of the catheter,

the catheter including a coolant delivery head distal relative to the anode, for receiving coolant from at least one inflow lumen of the catheter and for delivering a distributed flow of coolant liquid over the anode end of the x-ray tube, the delivery head having a coolant entry end fluidly connected to said inflow lumen and having a wall with a series of orifices for delivery of the coolant liquid toward the proximal direction of the catheter, toward and over said anode end, the orifices being spaced apart and distributed in position so as to spread the coolant liquid over substantially the entire area of the anode end so as efficiently to cool the anode, and

a coolant return space around the x-ray tube for collecting coolant liquid that has flowed over the anode, said return space being connected to an outflow lumen in the catheter for returning the coolant liquid through the catheter toward a proximal end of the catheter and out of a human body.

2. The apparatus of claim 1, further including a coolant reservoir tank connected to said proximal end of the catheter, for receiving coolant liquid returning from the x-ray tube, and a pump for delivering coolant liquid through said inflow lumen of the catheter.

3. The apparatus of the claim 1, wherein the coolant delivery head is generally cylindrical and has a proximal axial end that overlaps and essentially envelops the anode end of the x-ray tube.

4. The apparatus of the claim 1, wherein the coolant delivery head comprises a generally cylindrical body having two axial ends, a distal end distal of said wall and a proximal end proximal of said wall, the proximal end having centering tabs extending radially inwardly to grip the exterior of the x-ray tube and effective to center the x-ray tube within the catheter, the distal end forming said coolant entry space.

5. The apparatus of claim 1, further including a filter in the path of the coolant liquid upstream of said orifices, the filter being effective to filter out particles that could plug the orifices in the coolant delivery head.

6. The apparatus of claim 5, wherein the filter is located within the coolant delivery head.

5 7. The apparatus of claim 1, wherein the coolant liquid includes a surfactant suitable for reducing surface tension of the coolant liquid and for improving heat transfer.

8. The apparatus of claim 1, wherein the coolant liquid is degassed to eliminate bubbles.

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9. The apparatus of claim 1, wherein the catheter comprises two concentric extrusions, including an outer extrusion and an inner extrusion, the inner extrusion having radially inwardly extending ridges on its interior, positioned and sized to engage an exterior surface of the miniature x-ray tube, and one of the inner and outer extrusions having, on its surface facing toward the other, stand-off ridges that engage the surface of said other extrusion, forming between the inner and outer extrusions at least one coolant flow channel, serving as said inflow lumen of the catheter for inflow of coolant liquid toward the coolant delivery head.

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10. The apparatus of claim 9, wherein the ridges extending between the inner surface of the outer extrusion and the outer

surface of the inner extrusion are substantially continuous through the catheter, forming a plurality of fluid flow lumens through which coolant liquid flows toward the coolant delivery head, the plurality of lumens thus distributing the flow of inflowing coolant liquid around the circumference of the catheter such that in the event of a relatively sharp bend in the catheter, causing one inflow lumen to collapse, at least one other inflow lumens are available to assure continued flow.

11. The apparatus of claim 10, wherein the space between the outer extrusion and the inner extrusion forms at least three separate channels around the circumference of the catheter for inflowing coolant liquid.

12. The apparatus of claim 9, wherein the inner and outer extrusions are formed of thermoplastic or thermoset material.

13. The apparatus of claim 1, wherein the coolant liquid flows into the catheter at a temperature in the range of about 0°C to about 37°C.

14. The apparatus of claim 13, wherein the coolant flows into and back out of the catheter at a rate of less than about 150 cc per minute.

15. The apparatus of claim 1, wherein the catheter includes a flexible, extendable wall portion in an area of the catheter near the x-ray tube, said extendable wall portion having behind it a chamber in communication with said inflow lumen of the catheter through which coolant liquid flows en route to cool the x-ray tube, such that when the catheter is in place in the human body the coolant liquid can be pressurized so as to cause the extendable portion of the catheter wall to extend outwardly to engage tissue of the body lumen and thus to center the x-ray tube.

16. The apparatus of claim 1, wherein the x-ray tube is translatable axially within the catheter, in fore/aft direction, for adjusting the position of the x-ray tube in the body lumen without moving the catheter.

17. The apparatus of claim 1, including a temperature monitor positioned to monitor temperature of coolant liquid flowing out of the catheter, to verify flow of coolant over the x-ray tube.

18. The apparatus of claim 1, further including a temperature monitor positioned to monitor temperature of coolant liquid flowing into the catheter.

18A. The apparatus of claim 1, wherein said inflow lumen of the catheter within which coolant fluid flows toward the x-ray tube is in an outer portion of the catheter, said outflow lumen being at an inner portion of the catheter, said inflow lumen  
5 having a flexible outer wall such that a vacuum can be applied to the inflow lumen while the catheter is implanted, to shrink the diameter of the catheter, then the catheter can be re-expanded when coolant liquid is pumped through the catheter.

10 19. The apparatus of claim 18, including an outer extrusion surrounding an inner extrusion and forming an annular space between the lumens, the space being divided around its circumference into multiple said inflow lumens.

15 20. The apparatus of claim 1, further including pressure monitors in the inflow and outflow lumens of the catheter, for confirming the continued flow of coolant liquid.

20 21. The apparatus of claim 1, further including a coolant liquid reservoir connected to the inflow and outflow lumens of the catheter, and including a peristaltic pump for pumping coolant liquid through the catheter without contamination.

22. The apparatus of claim 1, wherein the inflow lumen is in

an outer portion of the catheter, and wherein the catheter has an outer wall forming an outer boundary of the inflow lumen, the outer wall being formed of low thermally conductive material so as to serve as an insulator to minimize heating of the coolant as it flows through the catheter and through the human body toward the x-ray tube.

23. A cooling system for a miniature x-ray tube capable of being delivered in a catheter to a desired location in a lumen of the human body, comprising:

a catheter having multiple lumens for carrying a liquid coolant, with the x-ray tube contained in a distal end of the catheter,

the x-ray tube having an anode end near the distal end of the catheter, and

at least two of the lumens of the catheter being generally coaxial and concentric, including an outer lumen serving as an inflow lumen for coolant liquid and having a closed distal end and an inner lumen serving as an outflow or return lumen for coolant liquid, the x-ray tube being positioned centrally and generally coaxially with respect to the inner lumen and positioned such that coolant liquid from the inflow lumen flows over the anode end of the x-ray tube, and returns in the proximal direction of the catheter through the inner outflow lumen.

24. The apparatus of claim 23, further including a coolant reservoir tank connected to said proximal end of the catheter, for receiving coolant liquid returning from the x-ray tube, and a pump for delivering coolant liquid through said inflow lumen of the catheter.

25. The apparatus of claim 23, wherein the coolant liquid includes a surfactant suitable for reducing surface tension of the coolant liquid and for improving heat transfer.

26. The apparatus of claim 23, wherein the coolant liquid is degassed to eliminate bubbles.

27. The apparatus of claim 23, wherein the catheter comprises two concentric extrusions, including an outer extrusion and an inner extrusion, the inner extrusion having radially inwardly extending ridges on its interior, positioned and sized to engage an exterior surface of the miniature x-ray tube, and one of the inner and outer extrusions having, on its surface facing toward the other, stand-off ridges that engage the surface of said other extrusion, forming between the inner and outer extrusions at least one coolant flow channel, serving as said inflow lumen of the catheter for inflow of coolant liquid toward the coolant delivery head.



28. The apparatus of claim 27, wherein the ridges extending between the inner surface of the outer extrusion and the outer surface of the inner extrusion are substantially continuous through the catheter, forming a plurality of fluid flow lumens through which coolant liquid flows toward the coolant delivery head, the plurality of lumens thus distributing the flow of inflowing coolant liquid around the circumference of the catheter such that in the event of a relatively sharp bend in the catheter, causing one inflow lumen to collapse, at least one other inflow lumen is available to assure continued flow.

29. The apparatus of claim 28, wherein the space between the outer extrusion and the inner extrusion forms four separate channels around the circumference of the catheter for inflowing coolant liquid.

30. The apparatus of claim 23, wherein the coolant liquid flows into the catheter at a temperature in the range of about 0° to 37° C.

31. The apparatus of claim 30, wherein the coolant flows into and back out of the catheter at a rate of less than about 150cc per minute.

32. The apparatus of claim 23, wherein the catheter includes a flexible, extendable exterior wall portion in an area of the catheter near the x-ray tube, said extendable wall portion having behind it a chamber in communication with said inflow lumen of the catheter through which coolant liquid flows en route to cool the x-ray tube, such that when the catheter is in place in the human body the coolant liquid can be pressurized so as to cause the extendable portion of the catheter wall to extend radically outwardly to engage tissue of the body lumen and thus to generally center the x-ray tube.

33. The apparatus of claim 23, wherein the x-ray tube is translatable axially within the catheter, in fore/aft direction, for adjusting the position of the x-ray tube in the body lumen without moving the catheter relative to the human body.

34. The apparatus of claim 23, including temperature monitors positioned to monitor temperature of coolant liquid flowing out of the catheter, to verify flow of coolant over the x-ray tube.

35. The apparatus of claim 23, wherein said inflow lumen of the catheter within which coolant fluid flows toward the x-ray tube is in an outer portion of the catheter, said outflow lumen

being at an inner portion of the catheter, said inflow lumen having a flexible partially collapsible outer wall such that a vacuum can be applied to the inflow lumen while the catheter is implanted, to shrink the diameter of the catheter, then the catheter can be re-expanded when coolant liquid is pumped through the catheter.

36. The apparatus of claim 35, including an outer extrusion surrounding an inner extrusion and forming an annular space between the lumens, the space being divided around its circumference into multiple said inflow lumens.

37. The apparatus of claim 23, further including pressure monitors in the inflow and outflow lumens of the catheter, for confirming the continued flow of coolant liquid.

38. The apparatus of claim 23, further including a coolant liquid reservoir connected to the inflow and outflow lumens of the catheter, and including a peristaltic pump for pumping coolant liquid through the catheter without contamination.

39. The apparatus of claim 23, wherein the inflow lumen is in an outer portion of the catheter, and wherein the catheter has an outer wall forming an outer boundary of the inflow lumen, the

outer wall being formed of low thermally conductive material so as to serve as an insulator to minimize heating of the coolant as it flows through the catheter and through the human body toward the x-ray tube.

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40. The apparatus of claim 23, further including an inflatable applicator balloon near the distal end of the catheter, sealed to the catheter and expandable outwardly from the catheter for positioning of the catheter and x-ray tube, and including a liquid flow channel from said outer lumen into the applicator balloon, to inflate the applicator balloon with coolant liquid, and a return flow channel from the applicator balloon through the catheter to said inner lumen, for flow of coolant liquid from the applicator balloon into the inner lumen and over the anode end of the x-ray tube, and including pressure regulator means for maintaining a desired pressure in the applicator balloon while allowing coolant liquid to flow through the applicator balloon and over the anode end of the x-ray tube.

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41. A cooling system for a miniature x-ray tube capable of being delivered in a catheter to a desired location in a lumen of the human body, comprising:

a catheter having at least one lumen for carrying a liquid

coolant, with the x-ray tube contained in a distal end of the catheter,

the x-ray tube having an anode end near the distal end of the catheter,

5 an applicator balloon connected to the catheter near the distal end of the catheter, the balloon being expandable out from the catheter when inflated by a fluid,

the catheter including a flow channel connecting said at least one lumen to the interior of the applicator balloon, and

10 fluid communication means in the catheter for providing fluid communication between liquid in the applicator balloon when inflated and the anode end of the x-ray tube, for static cooling of the x-ray tube by the coolant liquid which also inflates the applicator balloon.

15 42. The cooling system of claim 41, wherein the fluid communication means is arranged to provide for convection of liquid coolant when the anode is heated during use, so that cooling liquid continually flows over the anode end.

20 43. The cooling system of claim 41, further including a heat exchanger tube within the applicator balloon, connected to an inflow and outflow conduit whereby liquid coolant can be circulated through the heat exchanger tube to withdraw heat from  
25 the liquid in the applicator balloon with low flow impedance.

44. A cooling system for a miniature x-ray tube capable of being delivered in a catheter to a desired location in a lumen of the human body, comprising:

5 a catheter having multiple lumens for carrying a liquid coolant, with the x-ray tube contained in a distal end of the catheter,

the x-ray tube having an anode end near the distal end of the catheter,

10 an inflatable balloon near the distal end of the catheter, sealed to the catheter and expandable outwardly from the catheter for positioning of the catheter and x-ray tube, and including a liquid flow channel comprising one of said multiple lumens and carrying inflowing coolant liquid, the flow channel communicating  
15 with the applicator balloon to inflate the applicator balloon with coolant liquid,

the liquid flow channel continuing from the applicator balloon to flow the liquid over the anode end of the x-ray tube, and including an outflow channel comprising another one of said  
20 multiple lumens, positioned to carry liquid that has flowed over the anode in a return direction out of the human body, and

including pressure regulator means for maintaining a desired pressure in the applicator balloon while allowing coolant liquid to flow through the applicator balloon and over the anode end of  
25 the x-ray tube.